Application of a Dual Satellite Geolocation System on Locating Sweeping Interference

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***Abstract*—**This paper describes an application of a dual satellite geolocation (DSG) system on identifying and locating the unknown source of uplink sweeping interference. The geolocation system integrates the method of joint time difference of arrival (TDOA) and frequency difference of arrival (FDOA) with ephemeris correction technique which successfully demonstrated high accuracy in interference source location. The factors affecting the location error were also discussed.

***Keywords*—**Dual satellite geolocation system, DGS, geolocation, TDOA/FDOA, and sweeping interference

I. Introduction

INTERFERENCE is a problematic issue in satellite communications which corrupt rare spectrum resources and make the satellite capacity unusable. In the worst case, satellite operators have to pay outage compensation to their customers and it incurs unnecessary revenue loss. In addition, the non-saleable bandwidth due to interference limits the profit growth and business development of the company. Therefore, satellite operators have been proactively protecting their spectrum from interference by all means and trying to shorten the outage period when interference happens.

One of the solutions is to facilitate the carrier ID movement which is initiated by the sIRG (The Satellite Interference Reduction Group). The objective is to help satellite operators to quickly identify the interference source by extracting the information contained in the carrier ID insertion. The industry is driving to deploy the scheme for all the video carriers and then applying to all types of carriers in the next stage. This initiative requires equipment manufacturers to incorporate carrier ID into their hardware and an adoption period is needed before the scheme can be widely accepted in the industry. Hence, there is a demand on an immediate solution for interference mitigation.

Dual satellite geolocation (DSG) is a well developed method to identify the location of a signal transmitter in a satellite network. Its major application is to quickly locate the source of interference and recover the corrupted spectrum.

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Sometimes interference is due to human error on wrong satellite pointing or frequency setting, non-compliance of ground antenna side lobe pattern which transmitting to adjacent satellite or radar / radio signal pickup. In most of the cases, interference is caused by faulty function of customer equipment, such as faulty local oscillator in the uplink chain or RF signal pickup via damaged cables / connectors or loose connection.

The interference types can be summarized as follow:

- ASI (Adjacent Satellite Interference) (uplink or downlink ASI)
- Intentional jammer
- Unauthorized transmission
- Operator error (Wrong pointing, frequency, polarization, power, bandwidth or transmission time)
- Equipment problem (noise pickup, oscillator drift, non-compliance antenna pattern or spurious)

Traditionally, satellite operators have to request suspected earth station to provide spectrum plots of the uplink HPA output or perform on-off tests of the uplink equipment to investigate the source of interference. These methods are ineffective as they are not time efficient and require interruption to the normal operation of customers when performing on-off test. Sometimes customers may not be equipped with appropriate spectrum analyzers on site and they are not able to capture and provide the requested spectrum plots. When the DSG System is used, the time and effort put of interference investigation can be significantly reduced and enable the satellite operator to locate an interference source which is not coming from their customer's earth station. It also allows operators to detect un-intended interferences or interferences outside their satellite network where an on-off test is not practicable.

This paper presents of the use of a DSG system for locating uplink sweeping interference. Unlike a fixed modulated interference, locating a sweeping or CW liked interference is more difficult. If the interference is modulated, the rate of the modulation can be used to resolve the possible TDOA correlation. But, when the interference is sweeping or CW liked, the timing information could not be resolved and makes the geolocation process more challenging.

The DSG system - satID by SAT Corporation was used to detect the uplink location of the unknown sweeping interference occurred on AsiaSat-4 satellite. The process successfully identified the location of the two different interference sources. The accuracy check confirmed that the location error is better than the proclaimed capability of the DSG system.

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II. Technical Overview

The principle of a DSG system uses the technique of joint time difference of arrival (TDOA) and frequency difference of arrival (FDOA) multilateration which was described in [1]. When an uplink antenna (Interference Source) transmits a signal to a satellite (Primary Satellite), this uplink antenna is also transmitting a copy of the signal in a lower power level to a nearby satellite (Secondary Satellite). We can setup a downlink antenna system (Primary downlink antenna) which is pointing to the primary satellite to receive this interference. When another downlink antenna system (Secondary downlink antenna), which is sensitive enough and pointing at the nearby satellite, this low power signal is being received also.

Due to the difference of the signal path of the two satellite links, the downlink antenna systems observes a different time delay for the signals received. The resulting differential time offset (DTO) gives partial location information of the interference source.

Physically the two satellites are moving with respect to the ground and each other. Therefore, the downlink antenna systems see a different Doppler shift on the signals received. The resulting differential frequency offset (DFO) provides additional location information.

Based the position data of the two satellites, i.e. the ephemeris data, together with the DTO and DFO information, a line of position (LOP) can be computed and defined. By taking measurements of DTO or DFO at different times, additional LOPs can be defined. The intersect point of the two LOPs is the estimated location of the uplink interfering station. The principle is shown in Fig. 1.

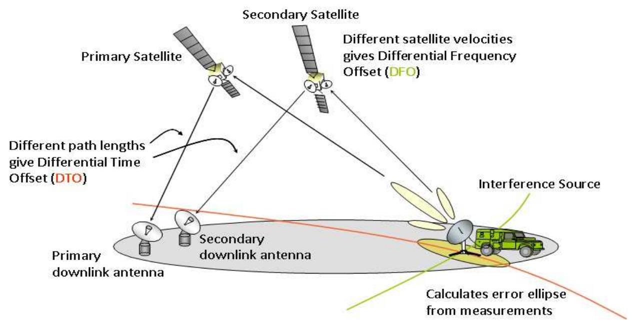

Fig. 1 Geolocation Principle of satID

Practically, there are some factors affecting the accuracy of the estimation. In the geolocation system, some additional methods are introduced to handle these factors for improving the accuracy which includes ephemeris error correction, desweeping tool and phase noise correction.

III. Application

In the literatures, the capability of DSG systems by using the joint TDOA/FDOA technique has been simulated and discussed thoroughly in theory and practice [2]–[4]. However, few examples of the application of a DSG system in the real life situation have been presented.

A. Background

In April 2012, AsiaSat used satID to geolocate two different unknown sweeping carriers on AsiaSat-4. The first one was a slow sweeping carrier moving through at the downlink frequency range of 3620MHz – 3625MHz (interference A) and the second one was also a slow sweeping carrier moving around at the downlink frequency range of 3655MHz – 3665MHz (interference B). The sweeping rate of interference A and interference B were bounded between 17kHz/min to 75kHz/min and 13kHz/min to 47kHz/min respectively.

Fig. 2 shows the spectrogram of interference A with the maximum hold and minimum hold comparison. Fig. 3 is the spectrogram of interference B and Fig. 4 illustrates the modulation analysis of the carrier which was suffering from interference.

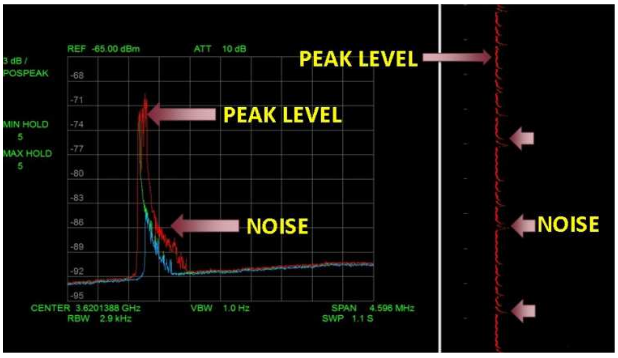

Fig. 2 Spectrogram of Interference A

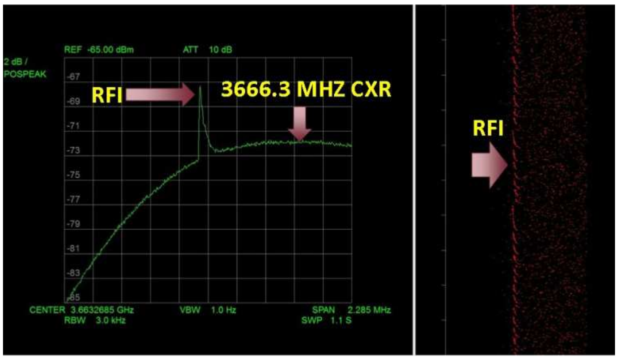

Fig. 3 Spectrogram of Interference B

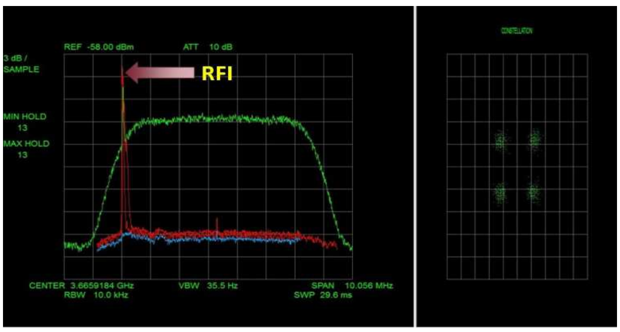

Fig. 4 Modulation Analysis of the carrier which was suffering from Interference B

The primary satellite, AsiaSat-4, is in geostationary orbit with a nominal longitude 122 deg E. For our case, AsiaSat-2 which was located at the longitude 120 deg E was chosen as the secondary satellite for the DSG.

B. Ephemeris Error Correction (EEC)

Ephemeris is the key information for the geolocation process. It contains the information for the positions and velocities of a satellite at various time epochs. During the geolocation attempt, AsiaSat had provided the latest ephemeris of both AsiaSat-4 and AsiaSat-2 to SAT. Any error of ephemeris will lead to inaccurate geolocation results. For example, if we use the public NORAD (North American Aerospace Defense Command) TLE (Two Line Element) ephemeris data, which is less accurate, for geolocation, the geolocation result error could be up to 1000km. To mitigate this, satID is designed with a tool, EEC, to correct the ephemeris uncertainty. EEC requires the location details of reference uplink stations for ephemeris correction. When we choose uplink reference signals for the EEC, it is better using the one to be coming from the same communication receiver as the interference was passing through to avoid the uncertainties in frequency translation.

As AsiaSat-4 uses Xenon Ion Propulsion System (XIPS), continual firing is required periodically everyday in a XIPS maneuver cycle. During a XIPS maneuver cycle, the ephemeris will keep changing and produce additional uncertainties. When geolocation of interference A and B was performed, AsiaSat-4 was under a XIPS maneuver cycle. Therefore, EEC was essential to improve the location accuracy. AsiaSat had provided the information required by SAT Corporation to facilitate EEC.

C. Desweeping Tool

satID is equipped with a desweeping tool for sweeping interference detection. It samples for a relatively wideband up to 6MHz to ensure capturing the interference signal within the sampling time. This tool has a special desweeping algorithm to enhance the correlation signal to noise ratio (SNR). The algorithm can realign the data by removing the time varying frequency shift at the system sampling rate.

By filtering the unwanted spectrum, a narrowband sample with stronger SNR can be obtained. For any fast sweeping interference which is present less than 0.3 s in the sampling bandwidth, satID will experience difficulty to acquire a confident estimation.

In our case, the frequency of both interference A and B were sweeping in nature. The system had to track the signal in wideband sampling and create a narrowband sample by applying the desweeping tool of satID to get a better correlation product. Fig. 5 and 6 show an application of the desweeping tool of satID.

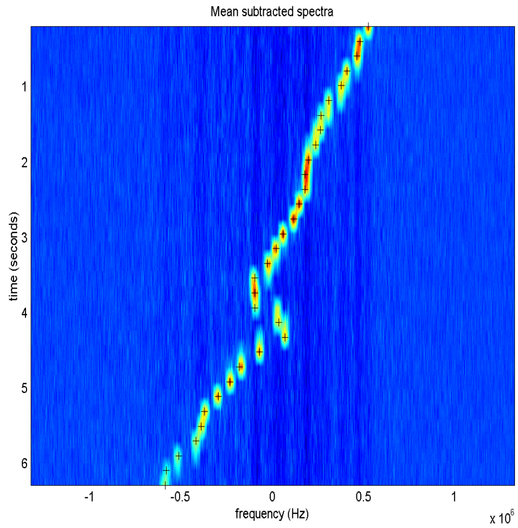

Fig. 5 Taking wideband sample of sweeping interference with time-varying characteristic in frequency

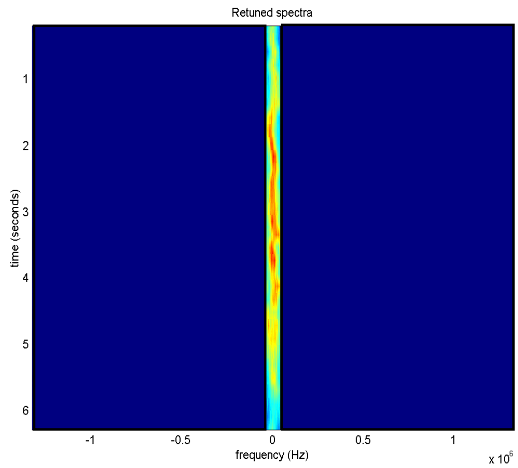

Fig. 6 Creating narrowband sample

D. Phase Noise Correction

After getting the narrowband sample, the system can calculate the correlation by using the cross ambiguity function (CAF) of the two received signals by successively applying different time and frequency offsets between each signal [5]. By varying the time and frequency offsets, a correlation surface is constructed until a peak occurs at the corresponding DTO and DFO value. In [6], the detailed procedure is described.

Although the interfering signals may be blocked with regular traffic, they are usually independent and do not correlate at any DTO and DFO value. However, due to the environmental and satellite turnaround oscillator effect, there is significant phase noise degradation and the correlation peak will be smeared. satID applies the technique and invention described in [6] for phase noise correction.

If the system can obtain enough processing gain for the interference, these additive noise components can be corrected and achieve the required accuracy.

E. Geolocation Results

The geolocation results of interference A and B are presented as follows:

1. Geolocation Result of Interference A

A total of six results were provided for the geolocation attempt of interference A. We used the results and calculated the average and variance which are shown as the mean position and variance in the table. Table I shows the geolocation result of the interference A. The results are mapped onto the satellite image in Fig. 7. According to the geolocation results, the interference source is located in the central region of Beijing, China.

TABLE I
GEOLOCATION RESULT OF INTERFERENCE A

	Latitude	Longitude
Result 1	39°56'35.90"N	116°27'20.53"E
Result 2	39°56'33.79"N	116°29'19.41"E
Result 3	39°56'21.85"N	116°28'55.95"E
Result 4	39°56'23.56"N	116°27'53.93"E
Result 5	39°57'42.70"N	116°31'47.91"E
Result 6	39°57'14.79"N	116°28'59.96"E
Mean Position	39°56'48.77"N	116°29'2.94"E
Variance	8.23418E-05	0.0006604

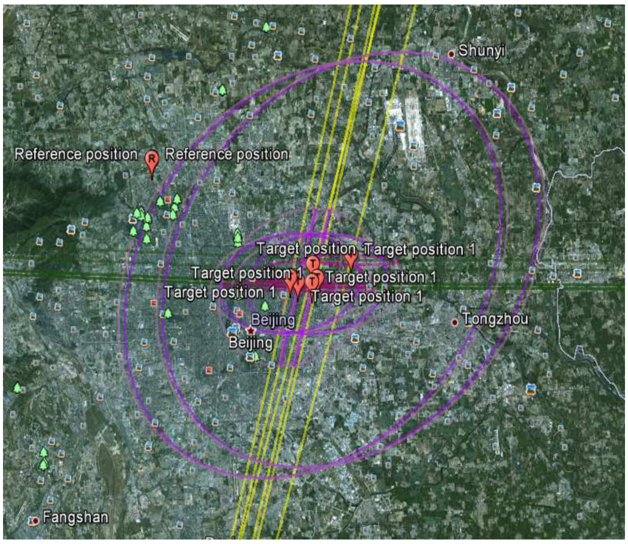

Fig. 7 Geolocation result of interference A

2. Geolocation Result of Interference B

Five results were given for the geolocation estimation of interference B. We used the results provided and calculated the average and variance which are shown as the mean position and variance in the table. Table II is a summary of the geolocation results of the interference B. The results are mapped onto the satellite image which is shown in Fig. 8. Based on the results, the location is near the northern part of Australia which is close to Galiwinku.

TABLE II
GEOLOCATION RESULT OF INTERFERENCE B

	Latitude	Longitude
Result 1	12° 4'33.87"S	135°37'36.43"E
Result 2	12° 4'36.53"S	135°35'57.39"E
Result 3	12° 4'30.16"S	135°37'11.98"E
Result 4	12° 4'48.58"S	135°35'45.79"E
Result 5	12° 4'52.74"S	135°35'12.07"E
Mean Position	12° 4'40.38"S	135°36'20.7"E
Variance	7.36229E-06	0.000286203

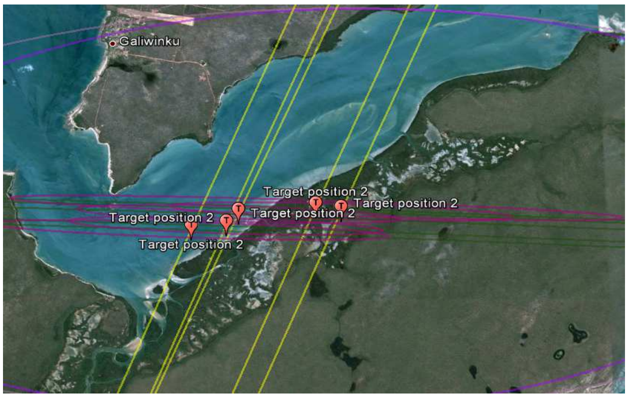

Fig. 8 Geolocation result of interference B

3. System Accuracy Check

Apart from geolocating interference A and B, an accuracy check was also performed by SAT Corporation to confirm the system accuracy of satID. A known uplink station (26°9'30"N, 91°47'0"E) in India was chosen as a reference. This reference uplink station was transmitting a DVB-S carrier in QPSK modulation and a symbol rate of 5.037Msym/sec. The system located it successfully without using EEC. Five geolocation attempts were performed for the accuracy check. The results are summarized in Table III. In Fig.9, the geolocation results, mean position and the real location are mapped on image for illustration.

The discrepancy between the real location and the mean position (26°9'56.54"N, 91°46'51.13"E) of the geolocation results is about 0.85km which is better than the proclaimed system capability of 3km. Statistically, the mean position is within 1.053σ in latitude and 0.152σ in longitude. It should be noted that the accuracy check is only used as a validation on the system performance but not a validation on the accuracy of the geolocation results of interference A and B as the carrier characteristics of the known reference carrier is different with that of the interference.

TABLE III
ACCURACY CHECK BY A KNOWN REFERENCE UPLINK STATION

	Latitude	Longitude
Result 1	26° 9'57.68"N	91°46'11.16"E
Result 2	26° 9'59.00"N	91°46'18.91"E
Result 3	26°10'13.57"N	91°48'32.48"E
Result 4	26°10'18.11"N	91°46'50.06"E
Result 5	26° 9'14.34"N	91°46'23.03"E
Mean Position	26° 9'56.54"N	91°46'51.13"E
Variance	4.9064E-05	0.000264242

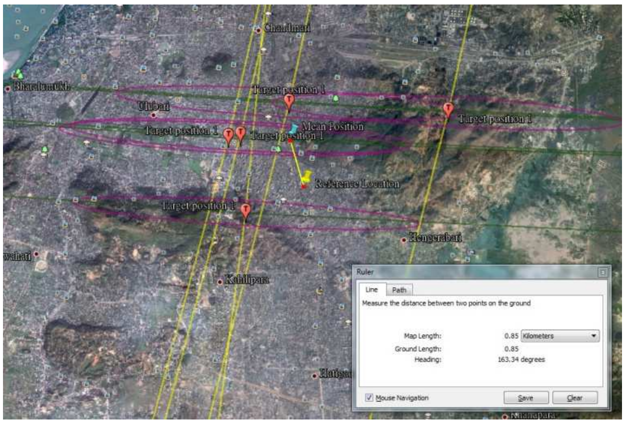

Fig. 9 Accuracy check by a known reference uplink station

IV. Discussions And Suggestions

When satellite payload design becomes more flexible in satellite communications, DSG system will be playing a more important role in the industry. By estimating the location of interference source, the use of flexible payload can alter the satellite receiving antenna pattern in space to suppress the uplink from the suspected interference area on the earth and avoid the harmful interference. The only constraint is when the customer station and the interfering station are very close to each other. The distance is depending on the roll off factor of the antenna beam isolation.

Moving forward, the challenges of using a DSG system are summarized and some possible solutions are suggested below.

A. Challenges in practice

According to the experience achieved in the application, the challenges encountered during geolocation process were discussed.

1. Measurement Uncertainty

The measurement is subject to various types of errors which were discussed in [7] – [11]. The dominant factor of uncertainty in geolocation is the ephemeris error. When accurate ephemeris is not available, the geolocation system is not able to provide a confident estimation. If satellite operator has to perform satellite maneuver, the current ephemeris will be changed. Updated ephemeris will not be available until the ranging and orbit determination processes are complete at least 24 hours after the maneuver. Although EEC can be used for ephemeris error compensation, geolocation result will still be affected by the precision of the location of the reference station. Therefore, the location of the reference station provided should be as accurate as possible.

2. Limit of Opportunity

DSG system requires an adjacent satellite for the DTO and DFO correlation calculation. According to the experience of SAT, the maximum separation between the primary and secondary satellite is about 10-12 deg for C band, 8-9 deg for 13.7-14.8GHz Ku band and 5-6 deg for BSS 17-18 GHz Ku band uplink frequency.

The minimum separation can be down to 1.5 deg. Nowadays, the geostationary earth orbit arc is very crowded and it is not too difficult to find an adjacent satellite within these degrees of separation. However, the constraints of adjacent satellite with available co-coverage, co-frequency and co-polarization may not be complied and limit the application opportunity of geolocation.

3. Require Cooperation from other Satellite Operators

Satellite operators have business concerns to disclose their payload and ephemeris information to protect their own interest. Even though it is possible that adjacent satellite operator would like to support and provide detailed ephemeris, the information may not be able to pass through in time. As a result, the ephemeris data could be expired already and not valid for a geolocation.

B. Suggestions

In the following section, some suggestions are proposed to solve the challenges discussed.

1. Establish Enhance Reference Location Database

Satellite operators can build up and maintain a database to collect the most updated and more precise uplink location details of their customers for developing reference location solution sets.

Consequently, when geolocation is required, satellite operators can apply the reference location solution sets for tracking the interference immediately. Small uplink antennae have a wider beamwidth and produce a stronger copy of signal to the secondary satellite than a large antenna. As a result, small antenna is preferred as a reference signal which can provide better correlation of DTO and DFO estimation.

Despite the preference of small antenna, it is suggested to have a combination of small and large antenna reference stations in the database as large antennas tend to transmit more static DVB and outbound traffic, while the small antennas tend to carry more dynamic and VSAT traffic which may not be always present on the spectrum.

2. On Orbit Fleet support

If satellites have steerable beams on board and the situation permits, satellite operators can consider adjusting the steerable beam of their satellite to the desired area to realize geolocation possibility. The actual feasibility is subject to the steerable beam coverage availability and customer occupancy on the beam.

3. Participation in sIRG for Alliance Support

sIRG formerly known as SUIRG (The Satellite Users Interference Reduction Group) is an independent industry association sponsored by satellite operators and satellite communication product vendors to share interference mitigation information and techniques. It is suggested that all operators actively participate in the group and share information and support when interference happens.

V. CONCLUSION

Despite the constraints mentioned in the paper, the process of DSG is effective, accurate and practical to be used for the satellite industry. It is suggested the satellite operators can establish and maintain their own enhance reference location database. In case geolocation is required, they can employ DSG solution and immediately provide adequate information to help the DSG service provider, e.g. SAT, for interference geolocation.

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